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Effect of Interaction Potential on Laser-assisted e-Ar Scattering

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The interaction potentials between electron and atom play an important role in electron-atom scattering. Using three potential models, the absolute differential cross section has been calculated by the second Born approximation theory. Results show that these model potentials are successful in the laser-assisted e-Ar scattering system. The influence of static potential, exchange potential and polarization potential on the absolute differential cross section is also analyzed and discussed.

Key words: Polarization potential, Exchange potential, Differential cross section, Laser field

I. INTRODUCTION

Laser-assisted electron-atom scattering has been extensively investigated both experimentally and theoretically over the last decade [1, 2]. However, it is very difficult in theory to deal with this problem because of its complexity. In order to calculate accurately the differential cross section, two pathways are necessary by the improvement of calculation method and electron-atom interaction potential. A classic theoretical treatment most widely applied to free-free transitions was based on the Kroll-Watson approximation (KWA) [3], which was much lower than the experiments [4, 5] for small angle scattering. Subsequently, a series of methods were developed to calculate one- and two-photon emission and absorption cross sections, such as a soft-photon, weak-field approximation [6], an approximate version of the Floquet R-matrix method [7], the second Born approximation (SBA) [8], *etc.* On the other hand, the model potential for atom was very simple in some literatures. Hokland *et al.* did not consider the influences of polarization potential [9]. The exchange effects were neglected by Čerkić *et al.* [10]. This suggests the effects of interaction potential must be overall taken into account. Sun *et al.* showed a complete potential model but did not show the interaction among static potential, exchange potential, and polarization potential [11, 12]. In this work, we perform a careful comparison among these potential, whose effects are analyzed and discussed.

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II. THEORETICAL TREATMENT

Since a laser mode contains a large number of photons, we may describe the laser field as a classical electromagnetic field $\mathbf{E}(t)$ and the corresponding to vector potential $\mathbf{A}(t)$

$$\mathbf{E}(t) = E_0\hat{\varepsilon}\sin\omega t \qquad (1)$$

$$\mathbf{A}(t) = \frac{c\mathbf{E}_0}{\omega}\cos\omega t \qquad (2)$$

where E_0 is the laser amplitude, ω is the laser frequency, c is the velocity of light, and $\hat{\varepsilon}$ is the polarization direction of the laser.

The solution of Schrödinger equation of an electron moving in the laser field and scattering form an atom potential $V(r)$ is as follows:

$$\Phi_{\mathbf{k}}(\mathbf{r},t) = \chi_{\mathbf{k}}(\mathbf{r},t) + \int \mathrm{d}\mathbf{r}' \int_{-\infty}^{t} \mathrm{d}t' G(\mathbf{r},t;\mathbf{r}',t) V(r') \Phi_{\mathbf{k}}(\mathbf{r}',t') \qquad (3)$$

here, $\chi_{\mathbf{k}}(\mathbf{r},t)$ is just the Volkov solution [13] (at time $t\to-\infty$), $G(\mathbf{r},t;\mathbf{r}',t')$ is the Green function. So we can obtain T matrix of the SBA theory with ν being photon exchange ($\nu>0$ for absorption and $\nu<0$ for emission)

$$T_{fi}^{(2)}(\nu) = T_{fi}^{(1)}(\nu) + T_{fi}^{(2)}(\nu) = J_\nu(\lambda_{fi})\tilde{V}(k_{fi}) + \sum_n \int \mathrm{d}\mathbf{k}_q \Big[(2\pi)^{-3}\tilde{V}(k_{fq})\tilde{V}(k_{qi}) J_{(\nu-n)}(\lambda_{fq}) J_n(\lambda_{qi})\Big] (E_i - E_q - n\hbar\omega + i0^+)^{-1} \qquad (4)$$

where $J_n(\lambda)$ is the Bessel function of the first kind and order n, $\tilde{V}(k_{\alpha\beta})$ is the Fourier transform of the atom

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potential

$$\tilde{V}(k_{\alpha\beta}) = \int \mathrm{d}\mathbf{r}\exp[-i(\mathbf{k}_\alpha - \mathbf{k}_\beta)\cdot\mathbf{r}]V(r) \qquad (5)$$

$$E_\alpha = \frac{\hbar^2 k_\alpha^2}{2m}$$

$$\lambda_{\alpha\beta} = (\mathbf{k}_\alpha - \mathbf{k}_\beta)\cdot\alpha_0$$

$$\vec{\alpha}_0 = \frac{e\mathbf{E}_0}{m\omega^2}$$

$$\alpha, \beta = i, q, f$$

The corresponding differential cross section with photon exchange ν is

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)^\nu = \frac{k_f(\nu)}{k_i}\left(\frac{m}{2\pi\hbar}\right)^2 \left|T_{fi}^{\langle 2\rangle}(\nu)\right|^2 \qquad (6)$$

Here, we presents these model potentials including coulomb potential $V_\mathrm{c}(r)$, static potential $\mathrm{V_s}(r)$, the polarization potential $V_\mathrm{p}(r)$ [10] and the static screen potential $V_\mathrm{se}(r)$ [14], where we use the atomic system of units ($\hbar$=e=m=1).

$$V_\mathrm{c}(r) = -\frac{Ze^2}{r} \qquad (7)$$

$$V_\mathrm{s}(r) = -\frac{Z}{r} + \sum_{i=1}^{Z}\int\frac{|\Phi_i(r')|^2}{|r-r'|}\mathrm{d}t' \qquad (8)$$

$$V_\mathrm{p}(r) = -\frac{\alpha_\mathrm{p}}{2(r^2+d^2)^2} \qquad (9)$$

$$V_\mathrm{se}(r) = -\frac{Z}{r}\sum_{i=1}^{3}A_i\exp(-\alpha_i r) \qquad (10)$$

where Z is the nuclear charge number of the atom, α_p is the electronic polarizability, A_i and α_i are the potential parameters (see [14]). For obtaining the influence of static potential, exchange potential and polarization potential on the absolute differential cross sections, we define V_1=V_s, V_2=V_se, V_3=V_se+V_p. Therefore, V_1 is static potential, V_2 concludes static potential and exchange potential [14], and V_3 concludes three aspects: static potential, exchange potential, and polarization potential.

III. RESULTS AND DISCUSSION

Figure 1 shows the potential energy curves of V_c, V_1, V_2, and V_3. Compared with $V_\mathrm{c}(r)$, the attenuation of the potential field of V_1, V_2, and V_3 is very rapid with the increase of the r, which indicates the three potentials are short-range potentials. Obviously, the model potential V is more appropriate by selecting the short-range potentials. In addition, the differences are very remarkable among V_1, V_2, and V_3. Thus, the effects of them on differential cross section need to be further studied.

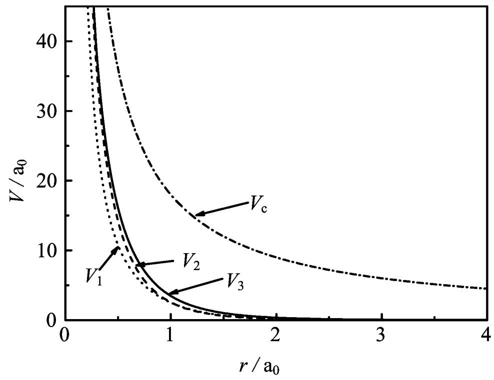

FIG. 1 Potential energy curve of V_c, V_1, V_2, and V_3.

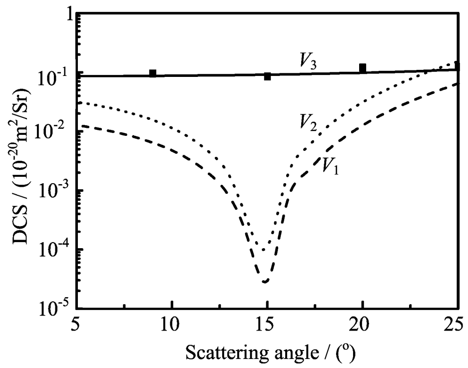

FIG. 2 One-photon absorption differential cross section (DCS) in $\mathrm{G_1}$. Solid boxes represent the experimental results from Ref.[5].

Here, we only consider that the incident electron beam direction is chosen to be parallel to the polarization direction of the laser and the momentum transfer for small angles because of the complexity of this problem ($\mathrm{G_1}$ geometry). The parameters are the same as those used in the experiment [5], the laser field frequency ω=0.117 eV and its intensity I=1.5×10^8 W/cm^2. For comparison, we have calculated the differential cross section employing the SBA with the values of V_1, V_2, and V_3 . These results along with the experimental results obtained by Wallbank and Holmes [5] are shown in Figs.2−4.

On the one hand, one can see that our theoretical results coincide with the experiment data, especially for V_3 potential, which present that the SBA method can describe the experimental results using the three different model potentials. The KWA or the first Born approximation theories are smaller 3−4 orders of magnitude than SBA [11]. The reason is that the KWA only considers the electron transformation from the initial state $\mathbf{k}_i$ to the final state $\mathbf{k}_f$ and the argument of the Bessel function is very small in the small angle scattering situation, which is only similar to the first Born approximation theory. Nevertheless, in the SBA theory, we consider not only the electron transformation

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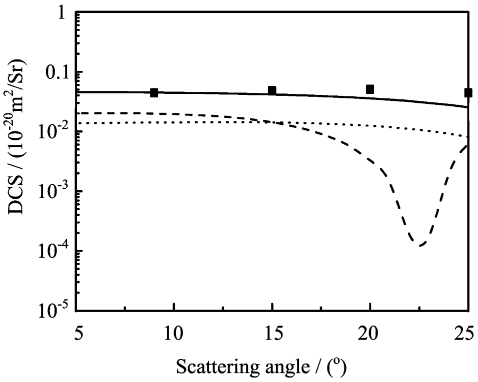

FIG. 3 Two-photon absorption differential cross section in G_1. Solid line, dotted line, and dashed line represent V_3, V_2, and V_1 results. Solid box is the experimental results from Ref.[5].

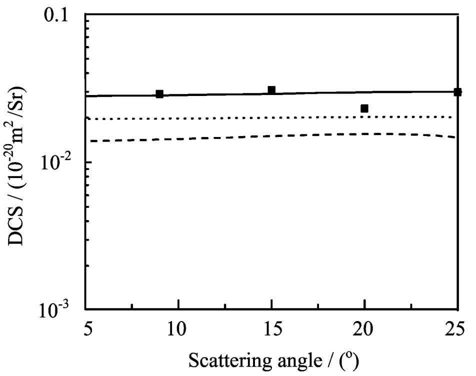

FIG. 4 Three-photon absorption differential cross section in G_1. Solid line, dotted line, and dashed line represent V_3, V_2 and V_1 results. Solid box is the experimental results from Ref.[5].

from $\mathbf{k}_i$ to $\mathbf{k}_f$, but also that from the initial state $\mathbf{k}_i$ to the intermediate state $\mathbf{k}_q$ and then from $\mathbf{k}_q$ to $\mathbf{k}_f$. The second amplitude is integrated for polar angles after the first collision (Eq.(4)), and the arguments of the Bessel function which appear under the integral can be large even for small scattering angle, so the second order amplitude is larger and becomes the main term in this situation.

On the other hand, the result of V_3 is better than that of V_2, and V_2 is better than V_1. We know that electrons in the near atom need a long time when electronic energy is lower. The model potential includes static potential, exchange potential, and polarization potential. V_3 is made up of the three aspects and its result is the best of them. V_2 is the static screen potential including static potential and exchange potential, and neglects the effect of polarization potential. V_1 only shows static potential and its result is worse than others compared with the experiment. Based on the above analysis, the exchange potential and the polarization potential are necessary for electron-atom scattering. The target atom is polarized by the Coulomb field of the incident electron and this effect is usually called the polarization potential [10]. The exchange potential is the exchange interaction between the transition electron and the electron in atom, and reflects a pure microcosmic benefit. It is found that the polarization potential and exchange potential play an important role in laser-assisted electron-atom scattering. After combining polarization potential or exchange potential, the results are obviously better than the static potential. We can draw the conclusion from Figs.2−4.

In general, the electron-atom interaction potential models' (V_1, V_2, and V_3) merits are single forms and easy calculations in theory, especially the V_3 potential (including V_{se} and V_{p}) has the concrete Fourier transform [10, 14] and makes the calculations more accurate and simple. To be specific, V_1 only shows the static potential and ignores other interactions. V_2 is the famous static screen Yukawa potential. V_3 is V_2 plus polarization potential, which describes the interaction between electron and atom more completely. However, V_2 and V_3 don't give a specific form of the static potential and exchange potential, especially for the static screen Yukawa potential that only includes the static potential and simple exchange potential [14]. It means that the exchange potential description is relatively simple and insufficiently precise. Therefore, our next work will focus on improvement of the exchange potential.

In addition, from Figs.2−4, we also find that discrepancies between the SBA results and experiments still exist. In such absolute measurements, the discrepancies between the different experiments may exceed 40% at particular energies and angles, reflecting the inherent experimental deviation. Hence, some errors in the experiment are unavoidable. Moreover, we only consider the homogeneous, linearly polarized laser field, however, this ideal laser field does not exist in fact. Though so many factors have not been considered, we have obtained encouraging results. The interaction potential results obtained in this paper are apparently successful, which may indicate the theory instruction for other more collision systems.

IV. CONCLUSION

The differential cross sections of e-Ar scattering in the presence of a CO_2 laser field have been calculated by the SBA theory. In order to study the effect of the interaction potential, we have compared the three different model potential results in the geometry G_1, and it is found that the electron-atom exchange potential and polarization potential are of significance in laser-assisted electron-atom scattering.

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[1] N. J. Mason, Rep. Prog. Phys. **56**, 1275 (1993).
[2] S. Geltman, J. Phys. B **35**, 4787 (2002).
[3] N. M. Kroll and K. M. Watson, Phys. Rev. A **8**, 804 (1973).
[4] B. Wallbank and J. K. Holmes, Phys. Rev. A **48**, R2515 (1993).
[5] B. Wallbank and J. K. Holmes, J. Phys. B **27**, 5405 (1994).
[6] L. B. Masden and K. Taulbjerg, J. Phys. B **28**, 5327 (1995).
[7] C. T. Chen and F. Robicheaux, J. Phys. B **29**, 345 (1996).
[8] J. F. Sun, S. H. Zhang, Y. H. Jiang, and G. Q. Yu, Phys. Rev. A **58**, 2225 (1998).
[9] S. Hokland and L. B. Madsen, Eur. Phys. J. D **29**, 209 (2004).
[10] A. Čerkić and D. B. Milošević , Phys. Rev. A **70**, 053402 (2004).
[11] J. F. Sun, X. F. Wang, Z. L. Zhu, and Q. B. Hu, Acta Phys. Sin. **56**, 2585 (2007).
[12] Q. B. Hu and J. F. Sun, Commun. Theor. Phys. **51**, 131 (2009).
[13] D. M. Volkov, Z. Phys. **94**, 250 (1935).
[14] F. Salvat, J. D. Martine, R. Mayol, and J. Parellada, Phys. Rev. A **36**, 467 (1987).

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